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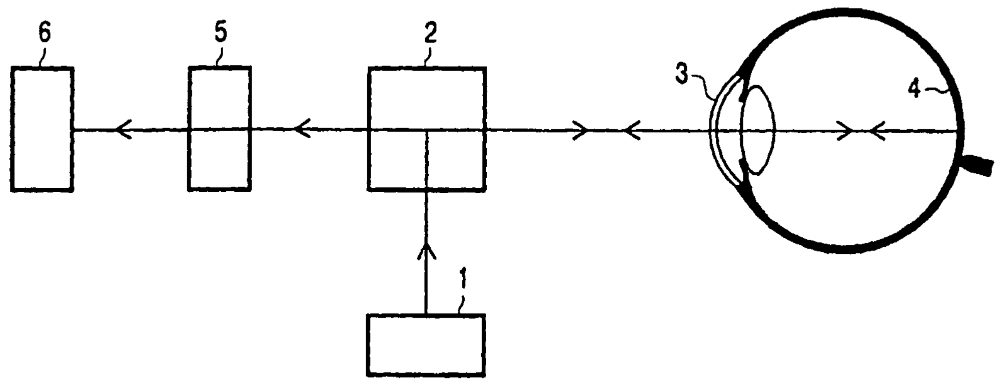
(54) Title: METHOD TO DETERMINE THE QUALITY OF EYE-OPTICS



(57) **Abstract:** The invention relates to a method to determine the quality of eye optics, wherein a light signal is passed into an eye, producing a spot image on the retina of the eye, that the spot image on the retina produces a secondary light signal that is measured outside the eye, and that from characteristics of the secondary light signal a measure is derived indicating the quality of the eye optics. An objective refractometer is utilized, and the signals coming from the refractometer are processed into a single parameter, which is a measure of the quality of the eye optics.

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Method to determine the quality of eye-optics

The invention relates to a method to determine the quality of eye-optics, wherein a light signal is passed into an eye, producing a spot image on the retina of the eye, that the spot image on the retina produces a secondary light signal that is measured outside the eye, and that from characteristics of the secondary light signal a gauge is derived indicating the quality of the eye optics.

The American patent specification US-A-4,560,259 discloses a method directed at determining correction parameters for the eye that relate to global refractive aberrations.

Generally speaking, the following observations may be made with respect to the process of visual perception in humans.

The human visual system can be divided into a number of elements that culminate in a conscious perception of these surroundings. Light coming from the surroundings enters the eye via the cornea, pupil and eye lens. Refraction of the light at the cornea and eye lens produces a projection of the surroundings on the retina. The retina comprises photoreceptors that convert the light from said image into electrical signals. These are transported by the eye nerve to the brain where further processing results in conscious perception. Vision is determined, among other things, by the quality of the image that is formed on the retina. Ideally, a point-like light source produces a point-like light spot on the retina. Due to various causes, the light spot on the retina will in reality be somewhat spread out. A generally known reason for this is the global (spherical and cylindrical) refractive faults that may be corrected by means of, for example, spectacles or contact lenses. In addition to the global refractive errors there are other

causes determining the quality of the retinal image. These include local refractive errors, diffusion of light and diffraction. These imperfections of the eye optics are corrected less easily. In the case of greatly increased diffusion of light in the eye lens the usual correction consists of replacing the natural lens with an artificial lens.

Such a method is known, for example from the American patent specification US-A-4,560,259. Said known method is directed at determining certain correction parameters for the eye.

When using objective methods to determine global refractive errors of the eye, the so-called objective refractor is applied. With such an objective refractor a light source is projected via a beam splitter onto the retina of an eye to be examined. A portion of the light falling on the retina is reflected and leaves the eye again via the pupil. Via the previously mentioned beam splitter and focusing optics this light is conducted to a detector, while analysis of the detector signal provides information about the global refractive errors of the eye.

The image-forming quality of the eye optics affects both the retinal image (ingoing direction) and the image formed by the light reflected by the retina (return direction) outside the eye.

According to the invention, this known objective refractor is utilized such that one single parameter can be obtained forming a measure of the quality of an image on the retina, thus including the non-global refractive errors. This parameter is a gauge for the question to which extent the patient's vision is determined by the optical characteristics of the examined eye. In this way it is possible to assess whether it is desirable to perform surgery, for example to perform surgery on a cataract.

In a following aspect of the method according to the invention, the same is characterized in that the refractometer is a knife-edge meter, which is provided

with a light source and preferably a double knife-edge that forms a slit, and that a series of measurements are carried out with the same, wherein the position of the focal point of the light source and slit are varied from in front of the retina to behind the retina of the examined eye, that for each focal point position a spot image distribution on the retina is determined wherein a difference signal in light intensity between an upper plane portion and a lower plane portion is determined, and that this focus-dependent difference signal is processed into a single number forming a measure of the quality of the eye optics, preferably by doing a curve fitting in order to determine the parameters in the difference signal function

$$f(s) = A \bullet \frac{\arctan\left(\frac{s-s_0}{W}\right)}{1+\frac{(s-s_0)^2}{W}},$$

wherein the parameters A, s, s_0 and W

have the following meaning:

A = amplitude of the difference signal function

s = the spherical refraction

s_0 = the optimal spherical refraction

W = a breadth parameter;

and that the amplitude parameter A is used as measure of the quality of the eye optics.

Another aspect of the method according to the invention is characterized in that the refractometer is a wave front sensor, wherein a light source projects a light spot onto the retina, and in that the secondary light signal coming from this light spot is measured by means of a lens grid of the wave front sensor, the pattern of secondary light spots that is measured by the lens grid being determined and recorded, in that the position of the

measured secondary light spots is compared with a previously determined position of such light spots in the absence of optical aberrations in the eye, and in that the difference signals measured are processed into a single number that is a measure of the quality of the eye optics.

It is advantageous for a two-dimensional Fourier transformation to be carried out on the signals coming from the wave front sensor, and for a null harmonic and first harmonics to be determined from the Fourier-transformed, the first harmonics subsequently being normalized to the null harmonic in order to provide a (dimension-less) number that forms a measure of the quality of the eye optics.

The invention will now be elucidated with reference to the drawings, in which:

- Figure 1 schematically shows the general construction and working of an objective refractometer;
- Figure 2 shows the general principle of the knife-edge test with which the method according to the invention can be applied in a first embodiment;
- Figure 3, shows another application of the knife-edge test according to Figure 2;
- Figure 4 shows the results of a curve fitting according to a first embodiment of the method according to the invention;
- Figure 5, schematically shows the principle of an objective refractometer used in a second embodiment of the method according to the invention; and
- Figure 6, shows some measuring results from the second embodiment of the method according to the invention obtained from a healthy eye and a cataract eye, respectively.

The general construction of an objective refractor is shown in Figure 1. A light source 1 is projected via a beam splitter 2 onto the retina 4 of the eye 3 to be examined. A portion of the light falling onto the retina is reflected and leaves the eye via the eye's pupil. Via a beam splitter 2 and focusing optics 5 this

light will reach a detector 6. Analysis of the detector signal provides information on the global refractive errors of the eye. The image-forming quality of the eye optics influences both the retinal image (ingoing direction) and the image formed outside the eye (return direction). This allows the light exiting the eye to be used for obtaining information about the optical quality.

The analysis of the quality of the eye optics is closely related to the choice of particular refraction measurement details. The parameter for describing the quality of the eye optics will be outlined in more detail on the basis of two methods of objective refraction measurement, with reference to the Figures 2, 3 and 4 and the Figures 5 and 6, respectively.

To objectively determine the refraction of an eye the so-called knife-edge test may be applied. This is known from the American patent specification US-A-4,560,259. The principle of the knife-edge test is depicted in Figure 2.

A point-like light source 1 illuminates an optical system, in this case consisting of one single lens 2. Positioned behind this lens is a knife-edge 3 that is movable along the optical axis. Behind the focal plane a screen 4 is positioned. This screen is illuminated by the light beams not blocked by the knife. Depending on the position of the knife on the optical axis, either the top or the bottom half of the screen will be illuminated. If the knife-edge is in the focal plane the screen will be illuminated evenly.

When applied to the eye, the reflection of light from the retina is used. This provides an optical system as schematically illustrated in Figure 3. The light source may, for example, be a linear one and there may be a double knife-edge so that a slit is formed. Both the slit and the source are imaged in the eye. Both images can be moved (simultaneously) with the aid of the projection optics in the refractor. Just as with the system shown in Figure 2, the light will be distributed in a specific

manner, this time in the pupillary plane of the eye. In the application as refractor, an even distribution of light is sought by means of adjusting the projection optics. In that case the images of slit and source are at the height of the retina. The projection optics now show the optimal refraction.

In addition to the optimal refraction according to the invention, it is with the aid of said optics also possible to determine a parameter for describing the quality of the eye optics. If the image of source and slit are deliberately projected in front of (or behind) the retina there will be an uneven distribution of light in the pupillary plane. The abruptness of the transition between the light and the dark part of the pupil is determined, among other things, by the quality of the eye optics. Poor eye optics produce a more even distribution of light in the pupillary plane than good optics. A detector measures the proportions of light in the top and bottom half of the pupillary plane. To determine the quality of the eye optics, the detector signals are analyzed as function of the position of the image of source and slit.

A possible manner of analyzing involves making a scan covering an area of (spherical) refractive errors in a range from -4 to +4 dioptres in 60 steps. The difference between detector signals from the top and the bottom pupil half are normalized to the sum of said detector signals. This signal is henceforth called $f(s)$. With the aid of data fitting the measurements are reduced to a number of parameters:

$$f(s) = A \bullet \frac{\arctan\left(\frac{s-s_0}{W}\right)}{1+\frac{(s-s_0)^2}{W}},$$

wherein s is the spherical refraction, s_0 is the optimal spherical refraction, A is the amplitude parameter and W is a breadth parameter.

An example of a scan is shown in Figure 4. This figure shows two scans: One relates to the vertical distribution of light in the pupil and one to the horizontal direction. Optimal refraction occurs at the point where $f(s)$ has a zero-axis crossing: the luminous intensity is then the same in both pupil halves. The example shown is of an eye with both spherical and cylindrical aberrations. Due to the cylindrical aberrations, the horizontal and the vertical scan have different optimal refractions. The amplitude parameter A, determined by this method as proposed by the invention, is a measure of the quality of the eye optics. Variations regarding illumination (slit-shaped or otherwise), and reproduction (knife forms and detector layout) and regarding the analysis of the signals obtained (distribution of the light in the pupil) may be chosen in various ways, all falling within the scope of the invention.

Figure 5 shows the principle of an automatic refractor based on the principle of the Shack-Hartmann wave front sensor. The light source projects a light spot onto the retina. A portion of the light will be reflected and will move as a spherical wave front in the direction of the pupil. The refractive properties of the eye lens and the cornea transform the wave front into a planar wave, at least in the ideal case. In a real eye there are deviations from a planar wave. The wave front sensor comprises a grid consisting of miniature lenses positioned in the pupillary plane. Behind each lens there is a projection of the light spot on the retina. In the case of the ideal planar wave this image will be located centrally behind each lens. This produces a regular pattern of light spots in the focal plane of the lens grid. This pattern is recorded by an image sensor. Deviations from the ideal planar wave will henceforth be indicated by $W(x,y)$, the

wave front as function of the position x,y in the pupillary plane. This wave front entails a displacement of the light spots. This displacement may be recorded as follows:

$$\Delta x = f \frac{\partial W(x,y)}{\partial x}, \quad \Delta y = f \frac{\partial W(x,y)}{\partial y},$$

f being the distance between lens grid and image sensor, and Δx, Δy the displacement of the light spots. By measuring the position of the light spots on the image sensor it is possible to reconstruct the wave front $W(x,y)$. This wave front contains the information of the local refractive properties of the eye in the pupillary plane.

The global spherical and cylindrical refraction leads to a scaling of the spot pattern. In the case of spherical aberrations this scaling is the same in all directions; in the case of cylindrical aberrations the scaling along the axis of the cylindrical aberration will differ from that perpendicularly thereto. In order to measure the global refraction it is not necessary to completely reconstruct the wave front. A very efficient manner to determine the refraction is by means of the two-dimensional Fourier transformed of the spot pattern. The spot pattern may be described as: $p(i,k)$, the number of elements both in the i and the k direction being N. The Fourier transformed of this signal is:

$$P(m,n) = \frac{1}{N} \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} p(i,k) e^{-2j\pi \left(m\frac{i}{N} + \frac{k}{N}\right)}$$

The mean distance of the spot pattern is obtained by the position of the first harmonics of the Fourier transformed. Because the wave front sensor measures the

local refraction at a large number of spots on the pupillary plane, it is possible to select the area in the pupil over which the global refraction is measured. This provides a more accurate refraction, especially for eyes that have a naturally large pupillary diameter. It is, after all, the rim of the pupil where the spherical aberration manifests itself. At the same time, however, the light from the rim of the pupil is detected less efficiently by the photoreceptors in the eye; this is the so-called Stiles-Crawford effect. By normalizing the spot pattern $p(i,k)$ it is possible to correct for this effect.

The refraction is not the only information to be derived from the Fourier transformed. Higher order-refractive errors, the so-called aberrations, provide a less regular spot pattern. The regularity of the spot pattern is provided by the intensity of the first harmonic. By, in accordance with the invention normalizing the intensity of the first harmonic to the mean intensity (the null harmonic), a dimensionless number is obtained that represents a measure of the regularity of the spot pattern, and thus for the optical quality of the eye.

Figure 6, shows an example of recordings by the wave front sensor of a healthy eye and of a cataract eye. The Fourier Parameter (FP) is mentioned both for the central 4 mm of the pupillary diameter and for the entire pupil (9 mm).

Scattering of the light results in a blurred spot pattern. This manifests itself in enlarged light spots with a lower maximum intensity. Because the adjacent light spots run into each other, the minimum intensity between light spots denotes a measure of the scattering of light in the eye optics. Normalizing this minimum intensity to the maximum intensity provides a dimension-less number that is a measure of the quality of the eye optics, irrespective of the amount of light reflected by the retina.

CLAIMS

1. A method to determine the quality of eye-optics, wherein a light signal is passed into an eye, producing a spot image on the retina of the eye, that the spot image on the retina produces a secondary light signal that is measured outside the eye, and that from characteristics of the secondary light signal a measure is derived indicating the quality of the eye optics, **characterized** in that an objective refractometer is utilized, and that the signals coming from the refractometer are processed into a single parameter, which is a measure of the quality of the eye optics.

2. A method according to claim 1, **characterized** in that the refractometer is a knife-edge meter, which is provided with a light source and preferably a double knife-edge that forms a slit, and that a series of measurements are carried out with the same, wherein the position of the focal point of the light source and slit are varied from in front of the retina to behind the retina of the examined eye, that for each focal point position a spot image distribution on the retina is determined wherein a difference signal in light intensity between an upper plane portion and a lower plane portion is determined, and that this focus-dependent difference signal is processed into a single number forming a measure of the quality of the eye optics.

3. A method according to claim 2, **characterized** in that a curve fitting is done on the difference signal in order to determine the parameters in the difference signal function

$$f(s) = A \bullet \frac{\arctan\left(\frac{s-s_0}{W}\right)}{1+\frac{(s-s_0)^2}{W}},$$

wherein the parameters A, s, s_0 and W

have the following meaning:

A = amplitude of the difference signal function

s = the spherical refraction

s_0 = the optimal spherical refraction

W = a breadth parameter;

and that the amplitude parameter A is used as measure of the quality of the eye optics.

4. A method according to claim 1, **characterized** in that the refractometer is a wave front sensor, wherein a light source projects a light spot onto the retina, and in that the secondary light signal coming from this light spot is measured by means of a lens grid of the wave front sensor, the pattern of secondary light spots that is measured by the lens grid being determined and recorded, in that the position of the measured secondary light spots is compared with a previously determined position of such light spots in the absence of optical aberrations in the eye, and in that the difference signals measured are processed into a single number that is a measure of the quality of the eye optics.

5. A method according to claim 4, **characterized** in that a two-dimensional Fourier transformation is carried out on the signals coming from the wave front sensor, and ~~in that a null harmonic and first harmonics are determined~~ from the Fourier-transformed, the first harmonics subsequently being normalized to the null harmonic in order to provide a (dimension-less) number that is a measure of the quality of the eye optics.

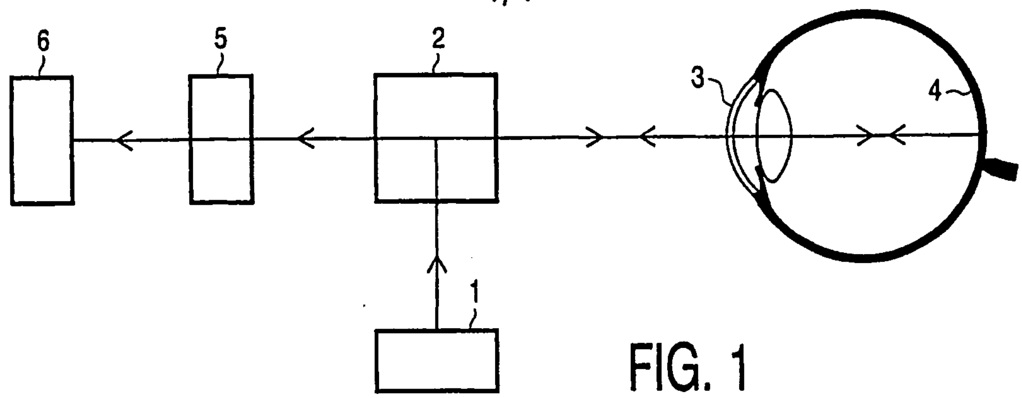
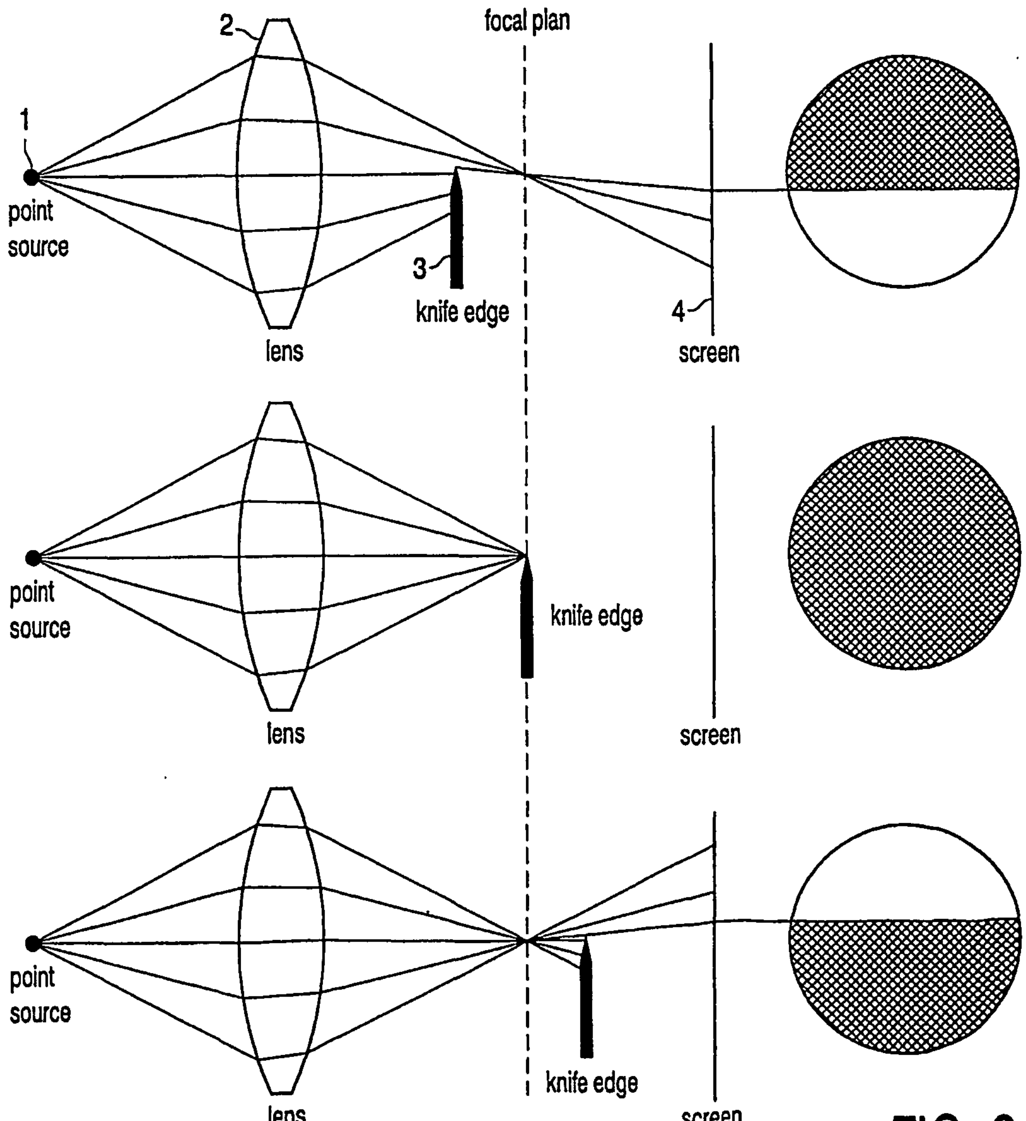

6
5
2
3
4
1

FIG. 1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1
point
source
3
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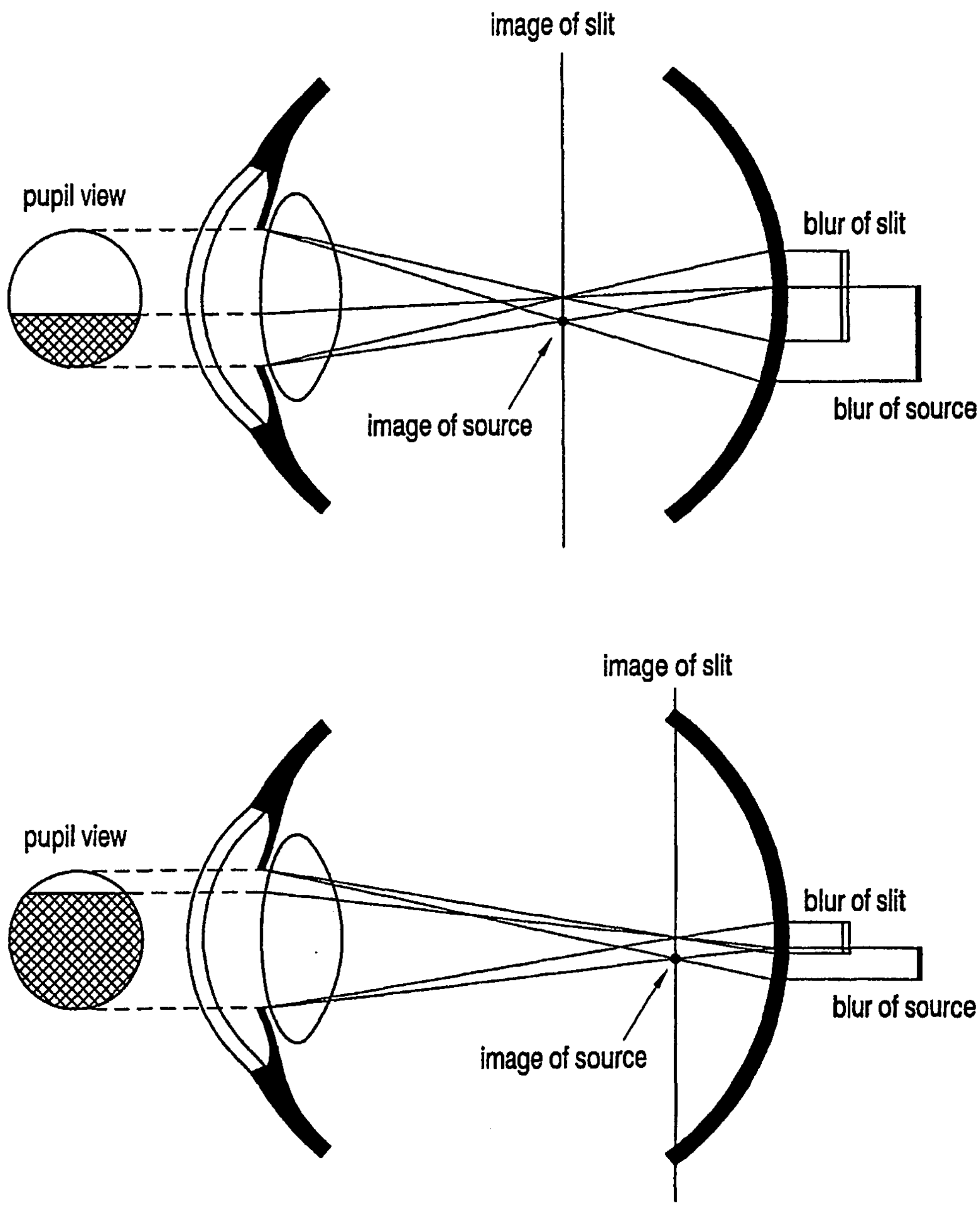
knife edge
lens
screen

FIG. 2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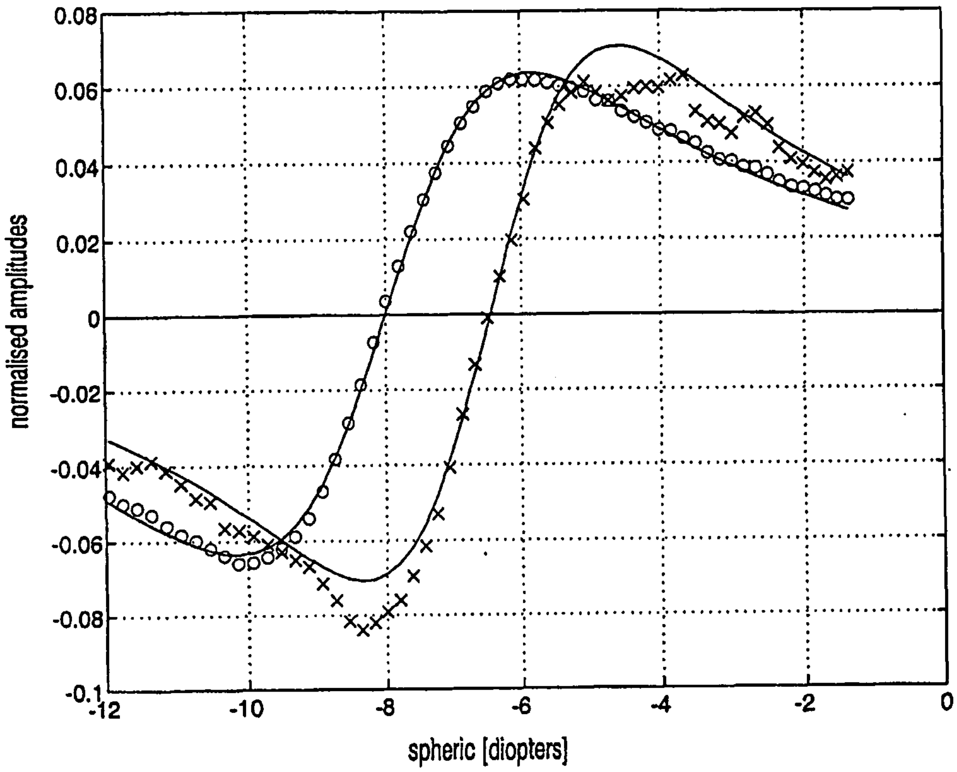
pupil view
blur of slit
blur of source
image of source

FIG. 3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0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-12
-10
-8
-6
-4
-2
0
normalised amplitudes
spheric [diopters]

FIG. 4

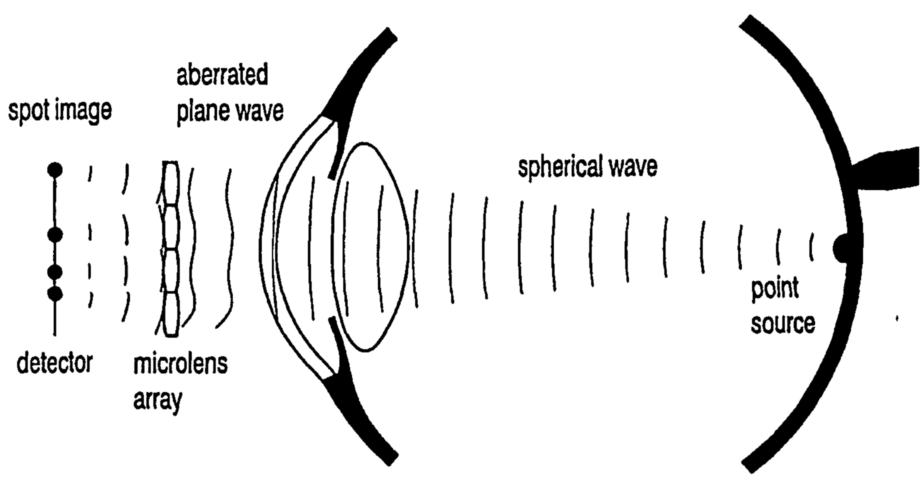
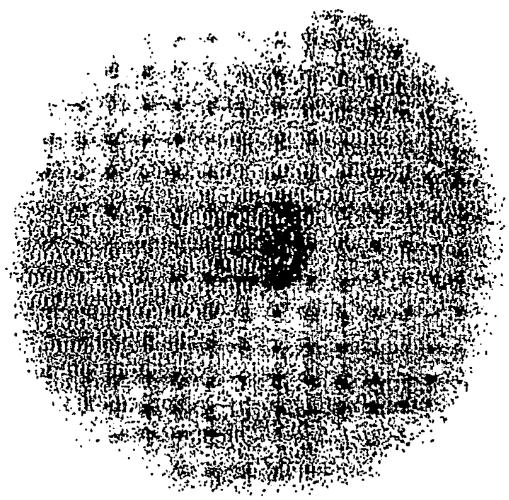

spot image
aberrated
plane wave
spherical wave
detector
microlens
array
point
source

FIG. 5

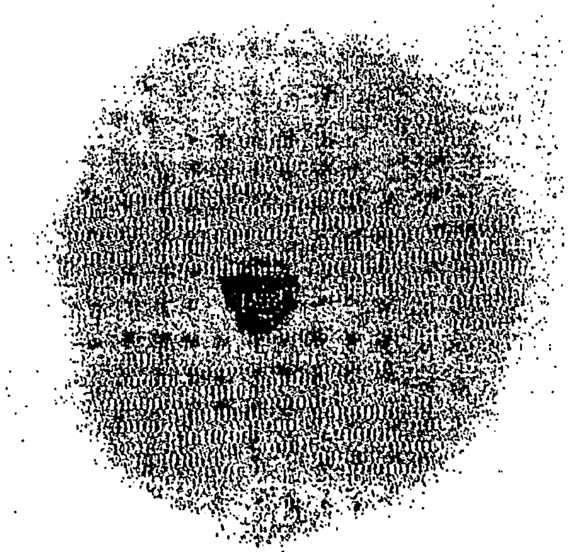
Wavefront Analyser recordings

a healthy eye of a 20 years' old person (visus 1.2)



FP (4mm.) = 1.58
FP (9mm.) = 1.1

a cataracteous eye of a 76 years' old person (visus 0.5)



FP (4mm.) = 0.78
FP (9mm.) = 0.44

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL 01/00545

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B3/103

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 963 300 A (AMT) 5 October 1999 (1999-10-05) column 6, line 51 -column 10, line 48	1,4,5
A	US 4 707 090 A (HUMPHREY) 17 November 1987 (1987-11-17) column 1, line 42 -column 7, line 48	1,2

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2001	21/11/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lemercier, D

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/NL 01/00545

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